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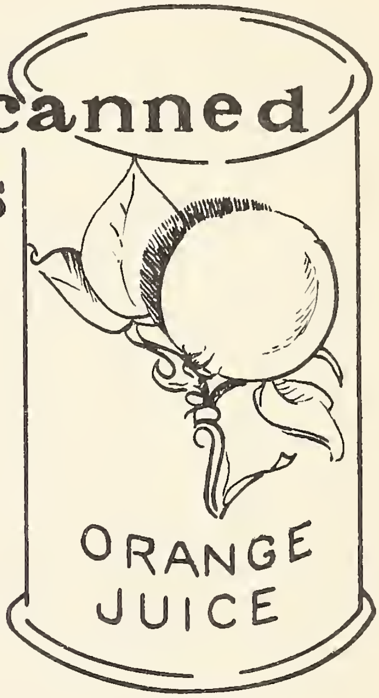
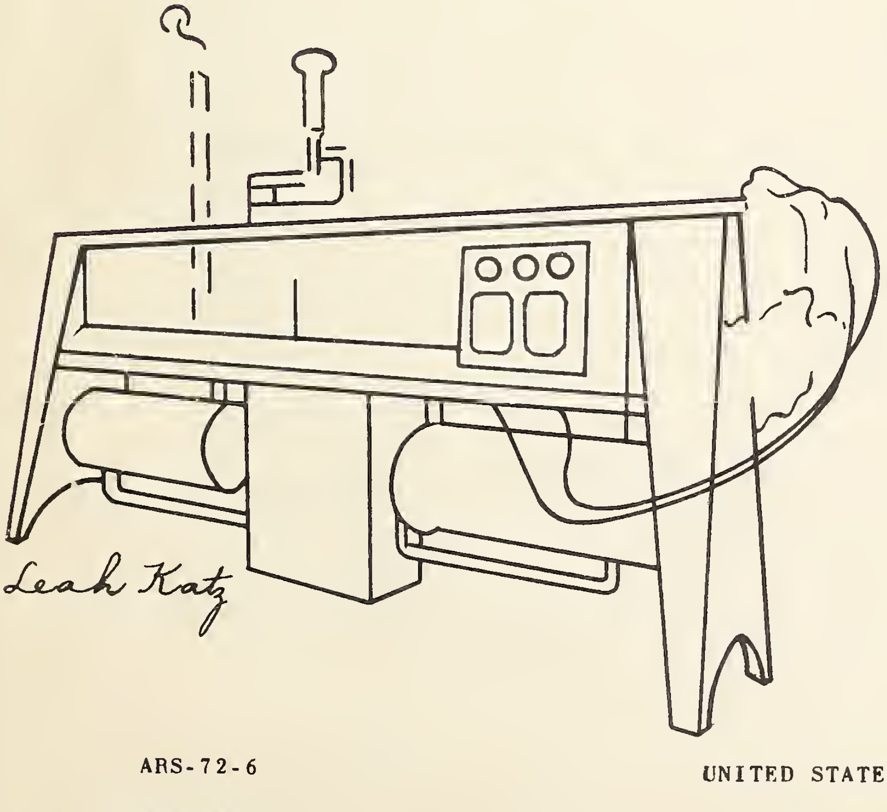
The effect of time and temperature of PASTEURIZATION on the quality of canned citrus juices





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THE EFFECT OF TIME AND TEMPERATURE OF PASTEURIZATION ON THE QUALITY OF CANNED CITRUS JUICES

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INTRODUCTION

A study was undertaken to obtain detailed information on the effects of different times and temperatures of pasteurization during canning on the quality of single-strength grapefruit and orange juices. The effects of varying the pH and of sweetening the juices were also observed.

In a history of citrus canning compiled by Timmons (37), Straughn in Puerto Rico in 1917 is credited with the first commercial application of flash pasteurization in processing grapefruit juice in a continuous tubular heat exchanger. Chace (5) in 1920 published a description with pictures of equipment for the continuous pasteurization of grapefruit juice and noted that "With grapefruit juice the sterilization temperature may run as high as 85°C. (185°F.) without deleterious effect, if the time of heating is kept between five and ten seconds." Irish (12) in 1928 (revised 1932) reported that undesirable changes in orange juice could be minimized by heating to 180° or 200° F. and chilling immediately to 40°F. or below in an enclosed system. He pointed out that enzymes were not destroyed by the ordinary pasteurization temperatures commonly used to kill yeasts and molds, but were destroyed at 190° to 200° F. Smalle (32) in 1930 described a method for canning orange juice by heating in a tank to 140°F. followed by flash heating to higher temperatures in a tubular pasteurizer. Stevenson (36) in 1934, describing the method used to can grapefruit juice, pointed out that a minimum temperature of 170°F. was necessary. Deaeration and flash pasteurization were advocated by Mottern and von Loesecke (22) and von Loesecke, Mottern, and Pulley (40) working in Florida in 1933-34, and by Joslyn and Marsh (13) working in California in 1934. Heid and Scott (10, 11) in 1937 investigated pasteurization of citrus juice from the point of view of pasteurizer design and operation. Parks (24) in 1940 found that the curd sometimes found in canned grapefruit juice could be prevented by adequate heat treatment. He found that adequate heat treatment consisted of heating to a minimum temperature of 190°F. for flash sterilization. Stevens (33) in 1940 described a method for processing citrus juices in which the extent and duration of the heat treatment is not only carefully controlled but is correlated particularly with the pH of the juice. Lueck and Pilcher (20) in 1941 reviewed data on the effects of stannous and ferrous ions on the stability of ascorbic acid in commercial canning of grapefruit juice. Boyd and Peterson (4) in 1945 recommended that juice be flash-sterilized using high-temperature short-time pasteurizers, heating to 225° - 240° F. in a few seconds, and immediately cooling to approximately 185 F. Joslyn and Sedky in 1940 (14) found that clearing of juices occurred at lower rates when heating had been at higher temperatures or for longer times. Loeffler (19) in 1941 observed that cloud is actually increased by flash pasteurization. Loeffler reasoned that loss of cloud may not be entirely due to enzymatic action. Stevens, Pritchett, and Baier (35) in 1950 contended that there are several enzymes involved in the loss of cloud in unheated citrus juices. Rouse and Atkins (30, 31) in 1952 and 1953 and Atkins and Rouse (1) in 1953 observed complete pectinesterase inactivation at temperatures ranging from 185° to 210° F. with grapefruit and orange juice, the temperature depending upon the kind of fruit and the time of heating. Bissett, Veldhuis, and Rushing (2) found that the cloud in a single strength orange juice was stabilized by heating to 190°F. in 17 seconds.

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[1] Resigned August 29, 1952.

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EXPERIMENTAL

Pilot Plant Equipment

Deaerator

The Pulley (27) deaerator consisted of a revolving saucer with perforated sides mounted within a shell and maintained under a vacuum of 29 inches (736 mm.). Pulley and von Loesecke (28) demonstrated that this device effectively deaerated citrus juices.

Pasteurizers

Three pasteurizers were constructed of coiled stainless steel tubes arranged within jackets. The tubing in the high speed pasteurizer was 0.116 inch I.D. with 0.020 inch wall (5/32 inch O.D.) and 22 feet long. The tubing in the medium speed pasteurizer was 0.242 inch I.D. with 0.035 inch wall (5/16 inch O.D.) and 33 feet long. The low speed pasteurizer tubing was 0.305 inch I.D. with 0.035 inch wall (3/8 inch O.D.) and 70 feet long. Automatic controllers regulated the circulating hot water or steam in the jackets.

Tubular cooler

A high-speed cooler unit consisting of 15 feet of stainless steel tubing 0.116 inch I.D. with 0.020 inch wall (5/32 inch O.D.) was constructed by coiling the tubing in a 2-1/2 inch pipe jacket 10 inches long. The medium and low speed tubular cooler consisted of 16 inches of jacketed tubing 0.242 inches I.D. and 0.035 inch wall (5/16 inch O.D.). An automatic controller regulated the flow of water in the jacket surrounding the coil.

Can sealing machine

A Pacific semiautomatic closing machine[3] was equipped to seal lids on 211 x 414 plain tin cans.

Can cooler

The can cooler was an inclined belt on which the cans spun or rotated in a horizontal position under sprays of water. This cooler reduced the temperature of juice in 211 x 414 plain tin cans from 190°F. to about 78°F. within a 3-minute retention time when the cooling water was 73°F.

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[3] The mention of trade products does not imply they are endorsed by U. S. Department of Agriculture over similar products not mentioned.

Pilot Plant Operation

The juice was usually deaerated before pasteurization. Juice was pumped through the pasteurizers at a rate of three-eighths of a gallon per minute in all cases. Retention time in the high speed pasteurizer was 1.75 seconds, in the medium speed pasteurizer 12.75 seconds, and in the low speed pasteurizer 42.6 seconds. The juice was cooled to 190°F. before filling the cans whenever a pasteurization temperature of above this temperature was used. During heating and cooling, the temperature of the juice was kept to ±1°F. of the specified values. The juice flowed directly into cans on a filling table. As each can was filled it was closed, inverted to sterilize the lid, and after 15 seconds placed in the can cooler. The times of heating and cooling the juice processed in the three pasteurizers are compared in Table 1. The high and low speed pasteurizers approach the performance of two widely used commercial types.

Description of Packs

Freshly extracted juice was obtained from a citrus cannery in the vicinity of the laboratory and handled as rapidly as possible. The properties of the various lots of juice, dates of packing, and numbers of experimental packs prepared from each lot of juice are given in Table 2.

Between December 16, 1947, and June 18, 1948, four lots of grapefruit juice and six lots of orange juice were obtained for use in the pilot plant. Each lot of juice was processed at about 10°F. intervals using the high (1.75 sec.) speed pasteurizer between 180° and 300° F. and the medium (12.75 sec.) speed pasteurizer between 140° and 210° F.

Between October 18, 1948, and May 27, 1949, eight lots of grapefruit juice and eight lots of orange juice were obtained at approximately 3-week intervals. From each of these sixteen lots of juice, packs of canned juice were prepared at a series of temperatures with each pasteurizer. With each lot of juice a series of seven packs were made, employing the high speed (1.75 sec.) pasteurizer at 185°, 190°, 195°, 200°, 210°, 220°, and 230° F. With each lot of juice another series of eight packs were made with the medium speed (12.75 sec.) pasteurizer at 160°, 170°, 180°, 185°, 190°, 195°, 200°, and 210° F. When the low-speed (42.6 sec.) pasteurizer became available, starting December 21, 1948, another series of eight packs were

Table I. Holding times for juice at different stages in pasteurizer treatment.

Location of the juice	Pasteurizer High speed	 Medium speed	 Low speed
	Seconds	Seconds	Seconds
In pasteurizer	1.75	12.75	42.6
Heater to cooler	0.32	3.50	3.50
In tubular cooler	1.23	0.51	0.51
Cooler to filler	1.04	0.3	0.3
Filling	15.0	15.0	15.0
Closing	8.0	8.0	8.0
Held inverted	15.0	15.0	15.0
In can cooler	180.0	180.0	180.0

prepared from each lot of juice at 160°, 170°, 180°, 185°, 190°, 195°, 200°, and 210° F. Thus, from each of these sixteen lots of juice fifteen separate packs of canned juice were prepared through December 6, 1948, and starting December 21, 1948, twenty-three separate packs were prepared from each lot of juice. Each pack consisted of about eighteen 12-ounce cans of which some were examined at once. Some were stored at 35°F. and some at 70°F.

To study the effect of varying the pH, two additional lots of juice marked "f/" in Table 2 were processed at a series of temperatures with the medium speed (12.75 sec.) pasteurizer. One lot of orange juice was obtained on January 4, 1949, and divided into five portions. Citric acid was used to adjust portions to 0.2 and 0.4 pH units below that of the juice as received, and sodium bicarbonate was used to adjust to 0.2 and 0.4 pH units above the juice as received. A series of packs was prepared from each portion with adjusted pH and of the juice as received. These five series of packs ranged from 3.2 to 4.0 pH. Each series of packs was processed at five temperatures, 180°, 185°, 190°, 195°, and 200° F. On January 24, 1949, the same procedure was followed with grapefruit juice through the range of 2.8 to 3.6 pH at 0.2 intervals.

The effect of sweetening the juice was studied with two lots of grapefruit and three lots of orange juice (five lots marked e/ in Table 2). On November 8, 1948, a lot of orange juice was divided into three portions. One portion unsweetened served as a check. Sufficient commercial sucrose was added to raise the total soluble solids of one part 3° Brix and the other portion 6° Brix. A series of packs was made with each portion of the juice with the medium speed (12.75 sec.) pasteurizer at 180°, 185°, 190°, 195°, and 200° F. This was repeated with orange juice on January 31 and February 15, 1949, using dextrose as the sweetening agent. A similar series of packs with grapefruit juice was prepared on November 15, 1948, using dextrose to sweeten and another on February 7, 1949, using sucrose.

A total of 135 packs was canned during the 1947-48 canning season and a total of 461 packs was canned during the 1948-49 canning season.

Analytical methods

Dextrose-tryptone agar compounded in the laboratory (25) was used throughout the project in microbiological analysis. When 1 ml. of grapefruit juice was added per plate, the pH was 5.8 and when 1 ml. of orange juice was added per plate the pH was 6.0 (26). Plate counts were always made on the raw and freshly canned juice. Organisms from colonies on low count plates, those from juice pasteurized at temperatures of 160°F. and above, were inspected with the microscope to identify as yeast or bacteria.

Cloud measurements were made on the canned juices after 6 months' storage at 70°F., using a modification of the Loeffler (18) procedure. The contents of each can were uniformly mixed prior to withdrawing a sample for testing. The stirred juice was poured into test tubes and allowed to stand overnight in the 70°F. room. Sodium benzoate was added to the juice to prevent fermentation. The next morning the top portion of the juice in each test tube was examined with an Evelyn colorimeter using a No. 720 filter[3] to measure the cloud or turbidity. Cloud density values (2-log of percentage light transmission) were recorded. Decreasing cloud density values indicate loss of cloud or suspended matter.

Pectinesterase activity was observed by the method patented by J. W. Stevens (34), with the permission of the California Fruit Growers Exchange, and by a rapid method developed in this laboratory (17). During the 1947-48 canning season, only the Stevens test was used, but during the 1948-49 canning season both enzyme tests were employed to determine enzyme

Table 2. Identification and Properties of the Juices Canned

Date lot of juice processed	Kind of juice	Series prepared[a]	Packs canned[b]	Total soluble solids	Acid as citric	Ratio Brix/acid	pH	Suspended solids	Peel oil	Ascorbic acid
		No.	No.	°Brix	Pct.			Pct.	Pct.	Mg/100 ml.
12-16-47[c]	orange	2	16	8.59	0.65	13.22	3.85	10.0	0.030	0.47
12-23-47[c]	grapefruit	2	16	9.33	1.35	6.91	3.36	-	-	-
1-6-48[c]	grapefruit	2	21	8.77	1.19	7.37	3.38	8.0	0.018	0.36
1-27-48[c]	orange	2	20	10.45	0.625	16.72	3.90	22.0	0.040	0.47
3-10-48[c]	orange	1	7	12.88	0.69	18.67	3.77	8.0	0.020	0.33
3-12-48[c]	grapefruit	1	6	11.2	1.21	9.25	3.40	13.0	0.016	0.37
3-24-48[c]	orange	2	7	16.43	0.60	27.40	3.75	17.0	0.020	-
4-22-48[c]	orange	2	12	9.49	0.63	15.06	3.97	8.0	0.020	-
6-15-48[c]	orange	2	15	10.83	0.50	21.66	4.17	13.0	0.040	-
6-18-48[c]	grapefruit	2	15	6.76	0.82	8.24	3.50	6.0	0.010	-
10-18-48[d]	orange	2	15	8.36	0.76	11.00	3.60	7.0	trace	0.38
10-25-48[d]	grapefruit	2	15	9.57	1.09	8.78	3.27	9.0	0.00	0.37
11-8-48[e]	orange	3	15	9.20	0.66	13.94	3.80	15.0	0.002	0.46
11-15-48[e]	grapefruit	3	15	8.80	0.92	9.57	3.50	10.0	0.022	0.40
11-29-48[d]	orange	2	15	11.15	0.77	14.48	3.73	14.0	0.020	0.51
12-6-48[d]	grapefruit	2	15	9.60	1.17	8.21	3.40	12.0	0.002	0.36
12-21-48[d]	orange	3	23	10.80	0.84	12.93	3.80	14.0	0.010	0.55
12-28-48[d]	grapefruit	3	23	9.90	1.11	8.92	3.30	11.0	0.010	0.42
1-4-49[f]	orange	5	25	12.1	0.85	14.32	3.60	15.0	0.020	-
1-10-49[d]	orange	3	23	12.18	0.78	15.62	3.53	18.0	0.014	0.67
1-18-49[d]	grapefruit	3	23	11.72	1.46	8.03	3.00	11.0	0.010	0.48
1-24-49[f]	grapefruit	5	25	10.83	1.34	8.08	3.23	10.0	0.010	0.47
1-31-49[e]	orange	3	15	13.08	0.95	13.77	3.40	17.0	0.030	0.71
2-7-49[e]	grapefruit	3	15	10.48	1.38	7.59	3.0	9.0	0.014	0.46
2-15-49[e]	orange	3	15	13.19	0.88	14.99	3.73	16.0	0.032	0.61
2-21-49[d]	orange	3	23	12.05	0.91	13.24	3.70	16.0	0.012	0.60
2-28-49[d]	grapefruit	3	23	11.68	1.46	8.00	3.30	9.0	0.01	0.49
3-14-49[d]	orange	3	23	11.8	0.93	12.76	3.52	14.0	0.006	0.58
3-21-49[d]	grapefruit	3	23	11.6	1.32	8.79	3.30	11.0	0.016	0.49
4-7-49[d]	orange	3	23	12.5	0.95	13.16	3.55	11.0	0.012	0.63
4-11-49[d]	grapefruit	3	23	10.73	1.0	10.73	3.1	10.0	0.004	0.47
5-16-49[d]	orange	3	23	12.3	0.68	18.09	3.80	16.0	0.016	0.46
5-27-49[d]	grapefruit	3	23	9.6	0.60	16.13	3.80	12.5	0.001	0.37

[a] In a "series" the only variable was temperature of pasteurization. The time of heating and juice were the same.

[b] A "pack" was composed of 18 identical cans.

[c] Lots of juice canned 1947-48 season.

[d] Regular lots of juice canned 1948-49 season at approximately 3-week intervals at series of temperatures with each pasteurizer.

[e] Lots of juice used for special studies of sweetening effects, series of packs at various temperatures with medium speed (12.75 sec.) pasteurizer only.

[f] Lots of juice used for special studies of pH effects, series of packs at various temperatures with medium speed (12.75 sec.) pasteurizer only.

activity on the same packs. During the period of July 13 to 16, 1948, cans of 25 packs that had been stored from 3 to 6 months were examined by the Stevens test (34), the same method used immediately after canning, for enzyme activity.

Viscosity measurements were made with a Stormer viscosimeter[3] in a constant temperature room at 70°F., where the whole assembly including samples was at a uniform temperature. The time for 100 revolutions was measured by an electric timer connected to a capacity actuated relay. The timer was calibrated directly in 0.1 seconds, but 0.05 seconds were estimated. At least five measurements were used in calculating the means reported. These measurements usually agreed within 1/10 second, and if aberrant values were encountered, additional measurements were made until their effect was of no importance. Viscosity for convenience is reported as apparent relative viscosity, the ratio of the viscosity of juice to that of distilled water. Absolute viscosity can be obtained by multiplying the reported relative viscosity by 0.009787 poises, the absolute viscosity of water at 70 F. DuBois and Murdock (8) suggested that the term "apparent" viscosity is appropriate with orange juice because of the effects of pulp content.

Acid, total soluble solids, and recoverable oil were measured on each lot of fruit juice received. Acid, as citric, was determined by titration with standard sodium hydroxide. The total soluble solids was determined with a Brix spindle. The recoverable oil was determined with Curl's modification of the R. B. McKinnis apparatus (6).

Taste testing was done by a panel of personnel at the laboratory using a triangle difference test described by Boggs and Hanson (3). The taste tests were conducted on packs after 6 months' storage at 70°F. A system of randomization was employed in the presentation of the juices to reduce bias to a minimum. Ruby-red glasses were used to obscure differences in appearance. The juices were presented at room temperature. As a study on the effect of temperature of pasteurization on flavor, comparison was made between packs receiving pasteurization at 230° and 185° F. with the high speed (1.75 sec.) pasteurizer. This was done with both grapefruit and orange juices and with each regular lot packed at 3-week intervals from October 18, 1948, to May 27, 1949, so that early, midseason, and late fruit was represented. Comparisons were also made between the orange juice packs prepared on March 7, 1949, at 160°F. and 210°F. (the extremes of temperature) with the low speed pasteurizer (42.6 sec.).

As a study of the effect of time of heating, comparisons for flavor were made between packs of the same lot of juice pasteurized in the high speed (1.75 sec.) and low speed (42.6 sec.) units both operated at the same temperature, 195°F. This was done with the regular lots of both grapefruit and orange juices packed between December 6, 1948, and May 27, 1949. Similar comparisons were made between packs from the same lot of orange juice with each of the above pasteurizers with the medium speed (12.75 sec.) pasteurizer operated at the same temperature, 195°F.

RESULTS

Fermentation developed within a few days at room temperature in many cans of both grapefruit and orange juice pasteurized at 140° and 150° F. during the first season. More swelled cans developed and burst in the packs pasteurized at 140°F. than among the cans with 150°F. pasteurization treatment. Not a single can from any pack that was pasteurized at 160°F. or above in this study showed signs of fermentation. For example, dextrose-tryptone agar plate counts of a lot of grapefruit juice was processed January 6, 1948, for raw juice and for canned juice at pasteurization temperatures up to 190°F. were: raw, 26,400;

140°F., 160; 150°F., 84; 160°F., 10; 170°F., 1; 180°F., 1; 190°F., 3. Inspection with the microscope of organisms from colonies frequently showed yeasts and bacteria present through 150°F. pasteurization treatment while at 160°F. and higher pasteurization temperatures only bacteria were found. These surviving bacteria were few in number and did not develop an active fermentation during storage and are not considered to be of significance.

Plate (viable cell) counts on dextrose-tryptone agar on raw grapefruit juice ranged from 12,800 to 760,000 and on raw orange juice from 36,600 to 880,000. In Table 3 the effect of time and temperature of pasteurization on the number of surviving organisms is shown. The counts decrease with increased temperature of heat treatment and time of heat treatment with both grapefruit and orange juices.

The turbidity or cloud as measured by cloud density of both canned grapefruit juice and canned orange juice was always greater in packs of the series made at higher temperatures of pasteurization as shown in Figures 1, 2, and 3. With the low speed (42.6 sec.), Figure 1, and medium speed (12.75 sec.), Figure 2, heating times, a sharp break occurred at 190°F. where cloud stabilization was attained. With these two pasteurization speeds, increasing the temperature of treatment to 200° or 210° F. did not further increase the cloud density. The charts represent average cloud densities of packs made at each temperature. Analysis of the

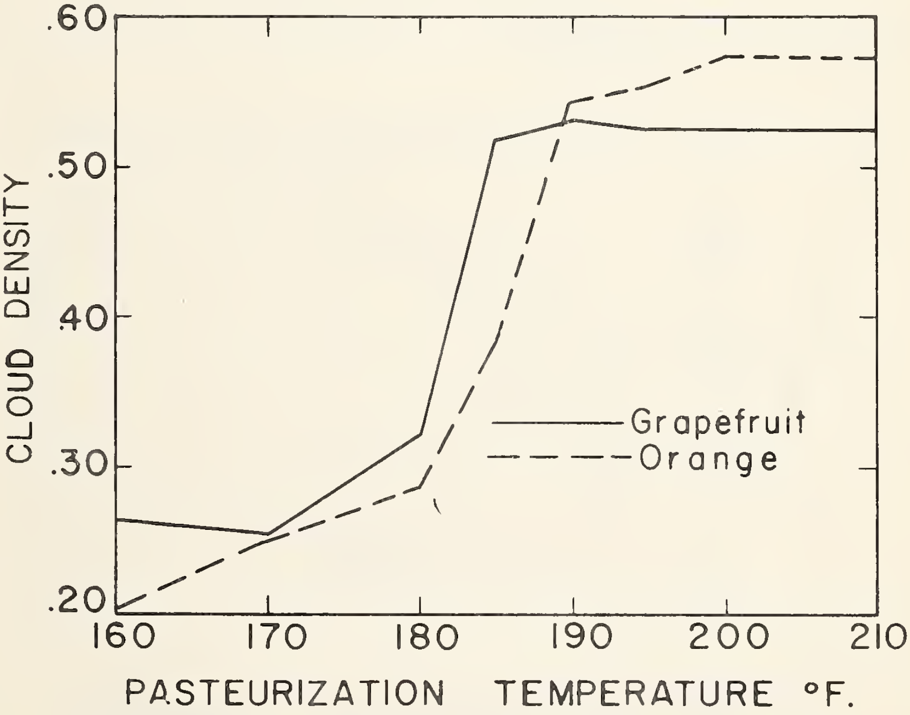

Figure 1. Average effects of temperature of pasteurization on cloud density with low speed (42.6 sec.) pasteurizer.

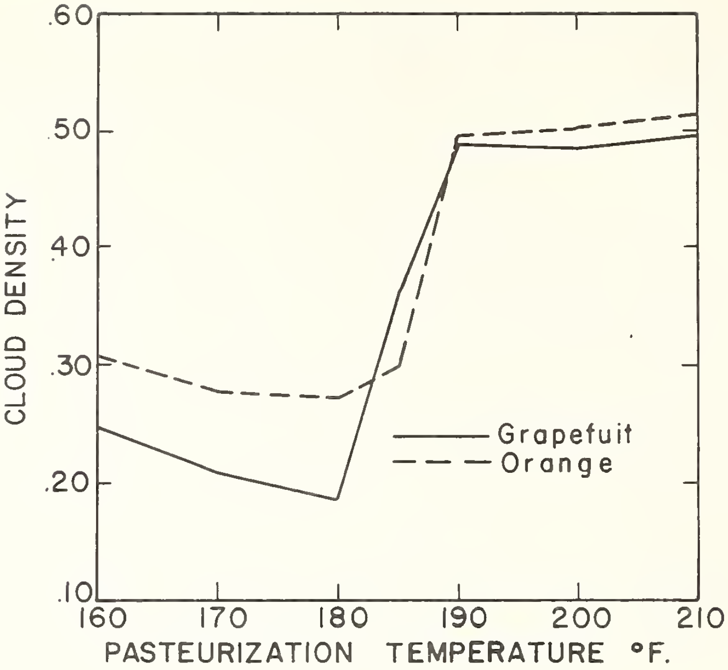

Figure 2. Average effects of temperature of pasteurization on cloud density with medium speed (12.75 sec.) pasteurizer.

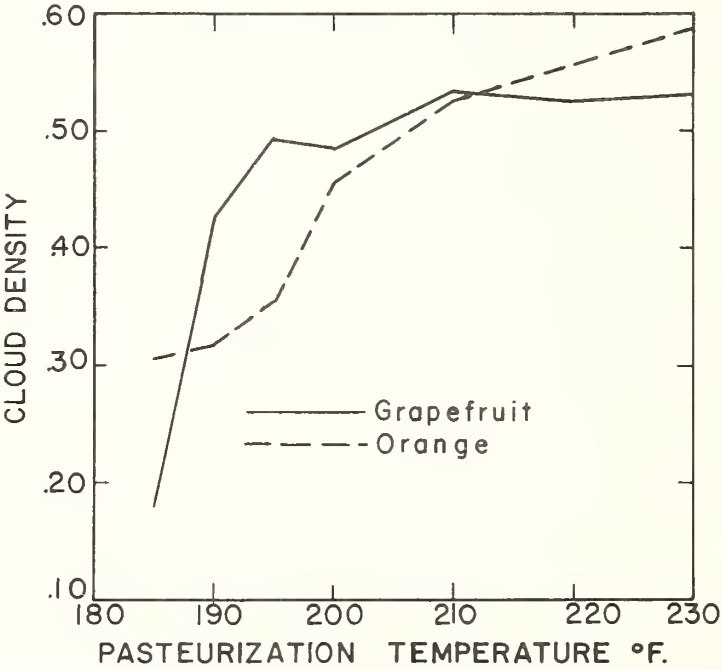

Figure 3. Average effects of temperature of pasteurization on cloud density with high speed (1.75 sec.) pasteurizer.

Table 3. Effect of time and temperature of pasteurization on the number of organisms surviving in canned single strength grapefruit and orange juice.

Pasteurizer speed	Pasteurization temperature 0°F.							
	160	170	180	190	200	210	220	230
	organisms per ml.[a]							
	GRAPEFRUIT							
High				16	9	10	9	4
Medium	13	14	16	3	3	1		
Low	27	16	3	1	1	4		
	ORANGE							
High				19	10	10	8	3
Medium	18	14	12	9	6	3		
Low	12	13	13	7	12	1		

[a] Each value is of the average number of colonies per plate on dextrose tryptone agar for eight packs made at 21-day intervals during the 1948-49 canning season.

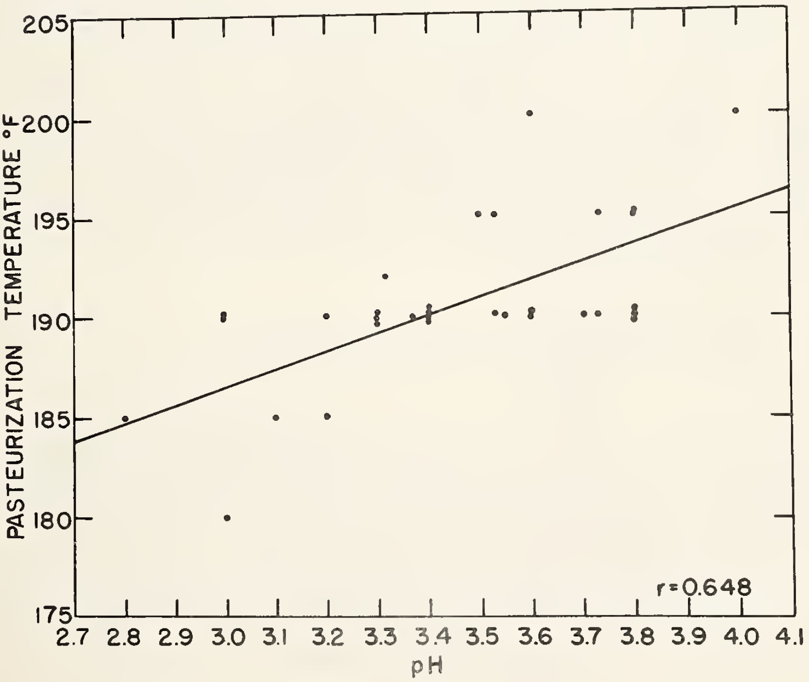

Figure 4. Effect of pH on temperature required to obtain cloud stability with medium speed (12.75 sec.) pasteurizer.

cloud density data indicates a highly significant difference between the results of 190°F. pasteurization and higher compared to 180°F. pasteurization and lower. Generally cloud stability was attained by heating to 190°F. The results of 185°F. pasteurization were intermediate, sometimes giving cloud stability and sometimes not. In some cases temperatures as high as 195°F. were required to achieve cloud stability in both grapefruit and orange juices with these two pasteurizers. Figure 3 shows the results with the high speed (1.75 sec.) pasteurizer. With grapefruit juice virtually complete cloud stability was obtained at 195°F. and above. With orange juice 230°F. it was sometimes necessary to effect maximum stabilization of the cloud although at 210°F. most of the stabilization apparently had been attained.

Figure 4 portrays the minimum temperature necessary to attain cloud stability with grapefruit and orange juices as related to the pH within the range of 2.8 to 4.0 pH. The temperature at which cloud stabilization was established in 31 series of packs was used. The figure includes all lots of juice canned during the 1948-49 season with the medium speed (12.75 sec.) pasteurizer except those involving the addition of sugar. The pH of the juice is correlated ($r = 0.648$) with the effectiveness of the heat treatments. The best fitting line was drawn and the equation found to be $Y = 160.0 + 8.86 x$. For an increase of 0.1 pH unit, it was necessary to increase the temperature of pasteurization an average of 0.886°F. (± 0.53°F. at P .01).

Titratable acidity in these juices was without observable effect on the minimum temperature of pasteurization for cloud stabilization. The total soluble solids within the range studied, 8.8° to 19.0° Brix, did not affect the temperature of pasteurization for cloud stabilization.

Enzyme inactivation was always achieved below 210°F. pasteurization temperature during the first operating season. During the second season it was noted that pectinesterase inactivation often corresponded exactly with the lowest temperature of pasteurization which resulted in cloud stabilization. A comparison between the lowest temperature of pasteurization to give cloud stabilization with the minimum temperature of enzyme inactivation is given in Table 4. The average temperatures are for 17 series of grapefruit juice and 18 series of orange juice packs in which the medium speed (12.75 sec.) pasteurizer was used. These averages include data from all series of packs canned during the 1948-49 season except two grapefruit and four orange juice series for which comparable data was missing due to exhaustion of the supply of samples. The Stevens enzyme test (34) appeared to be a more sensitive index than the rapid enzyme test (17).

The samples that were examined for enzyme activity before and after storage of 3 to 6 months at 70°F. showed no indication of enzyme regeneration.

Figure 5 illustrates the effects of time and temperature of heating on viscosity with a typical lot of grapefruit juice from which three series of packs were canned. It will be seen that higher viscosities are obtained with higher pasteurization temperatures; this was observed in 57 out of 69 series of packs. For each series of packs it will be observed that there was a definite dip or decrease in viscosity followed by a rapid increase. This dip was observed with 64 out of 69 series of packs of grapefruit and orange juice. Packs made with added sucrose and dextrose for both grapefruit and orange juice show similar dips. There was a general increase in viscosity when sweetening agents were added.

Higher levels of viscosity are associated with lower pH values in the grapefruit juice series. Parallel packs with orange juice yield viscosity curves grouped closely together so the effect was not clear.

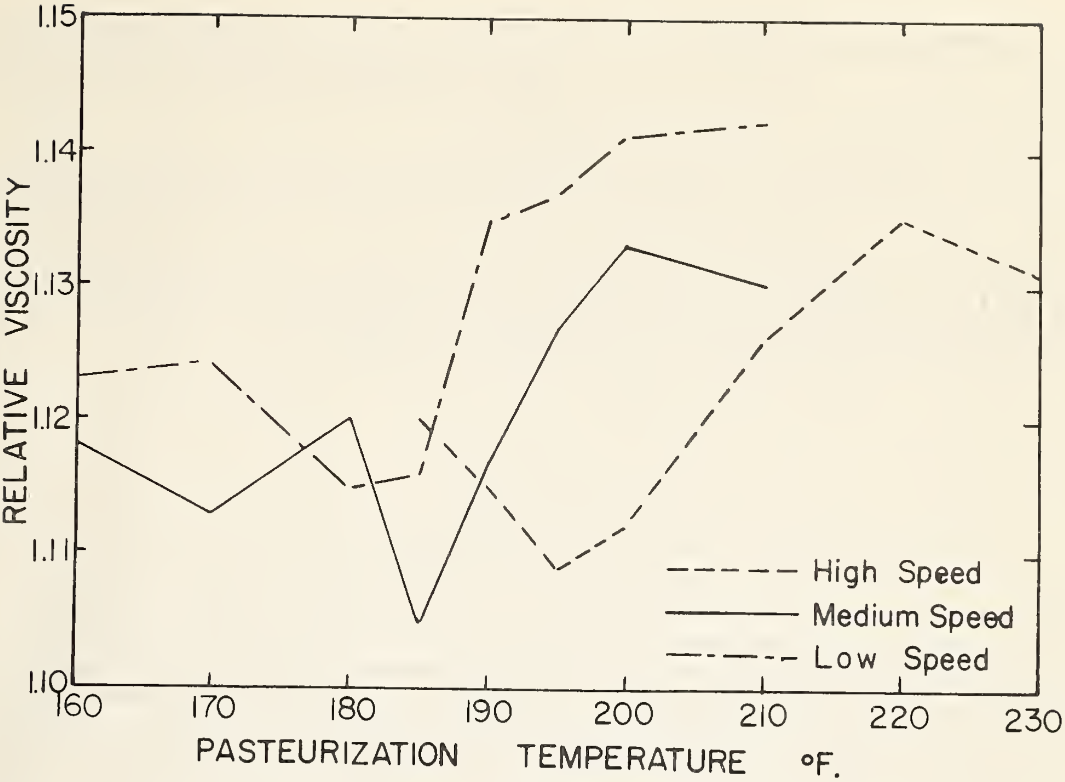

Figure 5. The effect of time and temperature of pasteurization on the viscosity of grapefruit juice prepared on April 11, 1955.

Table 4. Minimum average pasteurization temperatures observed for cloud stabilization and enzyme inactivation with the medium speed (12.75 sec.) pasteurizer.

Criterion	Grapefruit juice Mean	Orange juice Mean
	0°F.	0°F.
Cloud stabilization	190.0	192.5
Enzyme inactivation, Stevens (34)	188.0	195.3
Enzyme inactivation, Kew and Veldhuis (18)	184.4	189.2

The range of relative viscosities encountered was from 1,072 to 1,239 in the various packs of canned grapefruit juice and orange juice. Excluding Brix or pH studies the average range of relative viscosity for grapefruit juice packs was from 1.108 to 1.164 while orange juice packs ranged from 1.142 to 1.188. With both grapefruit and orange juices the lowest viscosity was found in juice canned in October. With grapefruit juice the highest viscosity occurred in packs canned in December while with orange juice the peak was reached in January.

The taste panel was unable to discriminate between packs of grapefruit that had received different treatments. This was true of the season's comparison of 230° vs. 185° F. pasteurization at high speed (1.75 sec.) and of packs where pasteurizations at high speed (1.75 sec.) and low speed (42.6 sec.) at 195°F. were compared.

The taste panel discriminated in some cases with orange juice and sometimes not. The panel was unable to distinguish between packs in the season's comparison of 230° vs. 185° F. pasteurization at high speed or between packs from a single lot comparing 210° vs. 160° F. pasteurization at low speed. In comparing one rate of heating with another, the panel successfully discriminated between high and low speed, and medium and low speed, but not between medium and high speed pasteurization of orange juice at 195°F.

DISCUSSION

The experience gained in the preliminary operation of the pilot plant the first season showed that in packs processed below 160°F. there was danger that gas would develop in the cans after canning and burst the containers. The microbiological examination showed that yeasts occasionally survived processing temperatures below 160°F. but were destroyed at or above that temperature. This fixed 160°F. as the lowest temperature to be used in the range studied in the pilot plant subsequently. The maximum processing temperature employed, 230°F., with the high speed (1.75 sec.) pasteurizer during the 1948-49 canning season, was chosen because it appeared well above the temperature where both enzyme inactivation and microbiological stabilization had been achieved. During the preliminary experiments enzyme inactivation was observed below 210°F. in all series and 230 F. appeared to be well above the minimum adequate pasteurization temperature.

Average plate counts were generally found to be as expected, decreasing with increasing temperature and time of pasteurization. Yeasts were relatively easily destroyed as previously reported by Nolte and von Loesecke (23).

Previous work by Ross (29), Moore, Wiederhold, and Atkins (21), and by Curl and Veldhuis (7), had shown that canned citrus juices could be stored for long intervals at 35°F. with little measurable deterioration. This enables uniform aging for 6 months at 70°F. followed by storage at 35 F. until analysis was accomplished. In this manner stabilization of the cloud could be studied under essentailly standardized conditions.

The observation that pectinesterase activity destroyed by pasteurization was not regenerated later on storage is important. If this had not been true, efforts to stabilize the cloud by pasteurization treatments would have been more complicated if not impossible. In evaluating the cloud stability data it should be remembered that these curves were drawn from average values. In actual practice the results from no series of packs duplicated any other series exactly. It is believed that this variability is inherent in natural products such as citrus juices. Small differences in the positions of points are undoubtedly without significance although the decided break in values is the result of many series of experiments. In commercial practice somewhat higher temperatures should be used to provide a margin of safety.

The data on the effects of pH on the temperature required to attain cloud stability shows considerable dispersion. The most probable line calculated from the 31 independent series of packs shows that a rise of 0.1 pH unit on the average raised by about 0.9°F. the temperature required to provide cloud stability.

Titratable acidity did not affect cloud stabilization. The hydrogen ion concentration and not the total acid content is the important factor.

Sugar is added to improve or stabilize the flavor of citrus juice. Both grapefruit and orange juices may be canned either unsweetened (natural juice) or sweetened under specified conditions (38, 39). The function of added sweetening ingredient does not include stabilization of the cloud.

The agreement between the temperature for cloud stabilization and pectinesterase inactivation is in general good. This agreement has led to the enzyme tests being proposed as an indication of proper pasteurization temperatures by Kew and Veldhuis (17). The picture unfortunately is not as clear cut as the early indications suggested. While agreement is in most cases good there are some discrepancies both above and below cloud stabilization. At first this was believed to be due to inaccuracy either in cloud or enzyme tests, but subsequent studies by Guyer, Miller, Bissett, and Veldhuis (9), Keller, Rice, McColloch, and Beavens (15), Kew (16), and others has led to the conclusion that the mechanism of cloud stabilization may be more complicated than was at first postulated.

Variations in viscosity were minor. The most pronounced effect was an increase in viscosity with the addition of sweetening agents. Low pH values favored higher viscosity, perhaps because of the extraction of more pectin by the more acid solutions. In general, raising the pasteurization temperature resulted in slightly higher viscosity and this could be explained by an increase in the amount of pectin dissolved. No explanation is advanced for the curious decrease in viscosity noted for temperatures slightly below those required for complete enzyme inactivation.

The failure of the taste panel to distinguish between packs of the same juice processed at 185° and 230° F. indicates that the highest temperature of pasteurization did not perceptibly affect the flavor of the juice in the short time it was processed above 185°F. It also indicates no perceptible impairment in flavor accrued from the use of the shortest time and highest temperature treatment. Apparently there is considerable latitude in the choice of heat treatments flavorwise.

Discrimination between juices heated for different times was possible for orange, but not for grapefruit. This is in agreement with the general opinion that the flavor of grapefruit is affected less by pasteurization than that of orange juice. They also detected a difference in flavor between medium and low speed heating for orange juice where the difference in time was 29.85 seconds. No difference in flavor was noted between the high and medium speed pasteurization when the time difference was only 11 seconds. Time was more important than temperature of heat treatment on the flavor of orange juice. However, within the ranges used in this study neither time nor temperature influenced the flavor of grapefruit juice perceptibly and orange juice only slightly. This is important because time and temperature within this range profoundly affect the stability of the cloud or appearance and viscosity or body of canned citrus juice.

SUMMARY

A study was conducted on the effects of time and temperature of pasteurization of grapefruit juice and orange juice with a pilot plant designed to duplicate as nearly as possible the actual commercial canning plant conditions. Destruction of microorganisms, the stability of the cloud or turbidity, "body" or viscosity, and detectable changes in flavor were observed.

Variables such as pH, titratable acidity, total soluble solids, and period of the canning season were considered.

It was found that below 160°F. pasteurization temperature yeasts survived and the canned citrus juices fermented. Low counts were encountered in all canned juices processed. At processing temperatures of 160°F. and above, no cans swelled or burst.

With both grapefruit and orange juices cloud stability was attained on the average at 210°F. with the high speed (1.75 sec.) pasteurizer. With the medium speed (12.75 sec.) pasteurizer 195°F. treatment temperature was sufficient. With the low speed (42.6 sec.) pasteurizer cloud stability was achieved at 185°F. and 190°F. The temperature at which the cloud stability was attained increased with pH; 0.1 unit increase required about 0.9°F. increase in pasteurization temperature. In industrial practice somewhat higher temperature should be used to provide a margin of safety.

The enzyme activity once destroyed was not regenerated on storage. The temperature at which pactinesterase was inactivated was usually the temperature where maximum cloud stability was attained.

As the pasteurization temperature increased in a series of packs made with a given lot of either grapefruit or orange juice the viscosity decreased and then increased. The effects of added sugar or of titratable acidity were very minor. Flavor differences after 6 months' storage at 70°F. were very minor between packs of the same lot of either grapefruit or orange juice canned at various times and temperatures of pasteurization employed in this study.

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